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Comparision of contact and contactless measuring methods for form evaluation

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Abstract

Coordinate measuring machines (CMM) are mostly used with contact sensors. High accuracy and very good results in repeatability are advantages of contact systems. Sometimes it is necessary to measure parts, which are not suitable for contact measurement. Usually they are compliant, stylus tip may scratch measured surface or the measured part have areas, which can not be reached by tactile probe. For this purposes there are also contactless methods of points collecting. Two contactless methods are selected for this study. One of them uses optical sensor based on CCD camera and another one uses computing tomography for contactless scanning of the part. Both systems have advantages and limitations. Not every part can be measured with all three systems. For example huge steel parts are not suitable for industrial tomographs, flatness cannot be satisfactorily measured by optical camera systems or measurement of line width on PCB is not achievable for stylus tip. This paper de-scribes differences among these three systems and refers possibilities of form deviations evaluation on example part.

Keywords : industrial tomography, coordinate measuring machine, form deviation

1. Introduction

Two coordinate measuring machines (CMM) were used for scanning of surface points of part. First one is the bridge type CMM Contura G2 from Carl Zeiss with contact system and contactless camera system and second one is industrial computed tomograph (CT) Metrotom 1500 with x-ray scanning system [6].

Coordinate measuring machine Contura G2 is embedded with articulating rotary dynamic sensor holder RDS for optical and contact sensors. VAST XXT measuring sensor for contact passive scanning was connected to this holder and ViSCAN optical camera sensor for contactless identifying of part's edges. Over 20 000 angular positions can be reached in 2.5° increments with RDS holder [5].

The fundamental differences, details and similarities of each individual method are presented in this paper.

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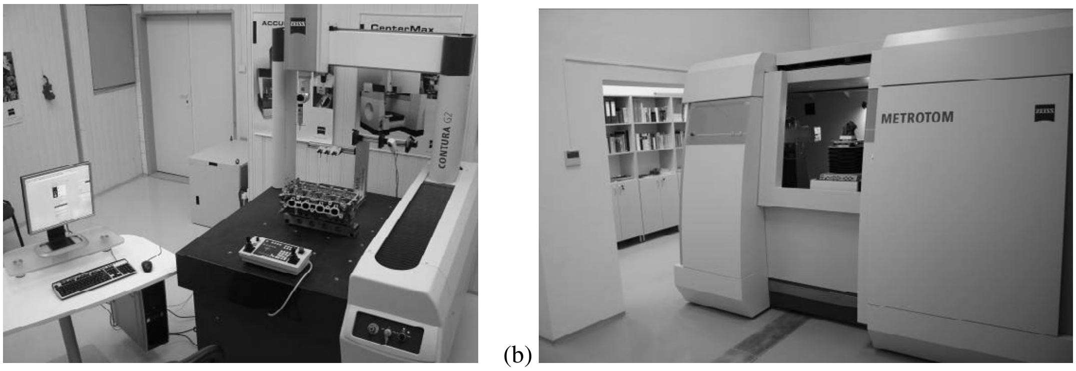


(a) (b)

Fig. 1. (a) CMM Contura G2 and (b) Metrotom 1500.

1.1. Coordinate measuring machine with tactile probe

The principle of operation of all tactile sensors is based on mechanical contact with the object of measurement. Then the signals are derived for further processing. Tactile sensors are classified into switching and measuring systems. Simple switching scanning systems operate on the tripod principle. If the scanning probe is deflected from an arbitrary direction, at least one of the switches is opened and this is processed as a switching signal. More sophisticated switching scanning systems introduce transformers to convert the mechanical signal into an electrical signal. With these directionally independent scanning behavior can be achieved. The uncertainty of measurement due to the sensor influence is smaller. In a measuring scanning system the sensor has path measuring systems generally in all three coordinate axes. If the scanning sphere is deflected in an arbitrary direction when in contact with the object of measurement, the magnitude of this deflection can be determined from the readings of the path measuring systems. The measuring point is determined by indication of the sensor coordinates, coordinates of measuring machine and value from stylus sphere correction. In order to measure several surface points it is not necessary to re-move the scanning probe from object of measurement each time. Sensor follows the surface of the object of measurement and always remains within its measuring range [1].

VAST XXT is a measuring sensor for scanning and single-point sensing. Maximum permissible error MP_E for length measurement with Contura G2 (size 7/10/6) with RDS holder and VAST XXT sensor is $MPE_E = (1,8 + L/300)$ µm, where L is measured length in mm (according to EN ISO 10360-2). Maximum permissible scanning probing error is $MPE_{THP} = 3,5$ µm for required measuring time 68 s (according to EN STN ISO 10360-4) and maximum permissible error for form measuring is $MPE_{RONt} = 1,8$ µm (according to EN ISO 12181 and VDI/VDE 2617 part 2.2) [2].

(a) (b) (c)

Fig. 2.(a) Tactile probe and (b) optical 2D image sensor and (c) computer tomography system.

1.2. Coordinate measuring machine with optical 2D image sensor

A visual sensor is regarded as a sensor similar to the human eye. It is common to use an image processing sensor as a visual sensor. The object of measurement is focused by the objective lens on to a matrix camera. The camera electronics convert the optical signals into a digital image which is used to calculate the measuring points. For evaluation it is necessary to have computer with the appropriate image processing software. For contour image processing the contours of the object are extracted from image by suitable mathematical algorithms. The resolution is directly limited by the pixel separation. High-quality devices interpolate within the pixel grid in a second step (subpixeling) and thus enable higher accuracies to be attained.

ViSCAN is an optical sensor for measuring of geometry which is not measurable with con-tact probes. Sensor consists of three parts: camera, objective and lightning unit. This camera sys-tem is used for scanning of contours. Because of that, it is necessary to set intensity and direction of light to optimal values. ViSCAN is connected to RDS holder which allows changing position of the camera during measurement to more than 20 736 positions. In our laboratory the objective with zoom factor 1× with area size (4,8×3,6) mm and resolution 6 µm is used. For optical 2D image sensor ViSCAN with auto focus the manufacturer declare $MPE_E = (10 + L/300)$ µm, where L is measured length in mm, maximum probing error 10 µm for 2D probing and 50 µm for 1D probing of auto focus (according to VDI/VDE 2617 part 6.1) [2].

1.3. Industrial computed tomography

Tomographic measuring procedure presented by Metrotom 1500 uses x-ray technology based on a simple principle: an x-ray source illuminates an object with electro-magnetic beams (the x-ray beams). The beams meet on a detector surface and are recorded in varying degrees of intensity depending on the thickness of the material and its absorption characteristics. The result is a two-dimensional gray-scale image (x-ray picture). Metrotom rotates the component 360° around its own axis, collects hundreds of x-ray pictures from different positions an produces a 3D image of whole volume of the part called point-cloud or data set [3].

Nowadays, the industrial tomographs are designed to scan with the high precision. Thanks to this, their use will be extended from the diagnosis area to the metrology area. In the metrology, they will improve the control of the parts with complicated shape, which could not have been measured until now.

The main industrial tomography areas of the use are as follows:

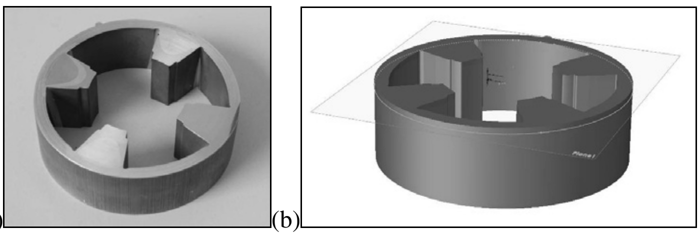
- testing: quality of the connections in assemblies, analysis of the porosity, analysis of the defects, inspection of the material,
- measuring the dimensions of inner and outer features,
- reverse engineering (obtaining the CAD model from the real part),
- comparing the nominal with actual geometry.

Maximum permissible error for length measurement with Metrotom 1500 is MPEE = $(9 + L/50)$ µm. Cylindrical measuring volume has size (300×Ø350) mm and flat detector panel has resolution (1024×1024) pixels. Power of x-ray tube can be adjusted up to 225 W (225 kV and 1 mA). Amount of power depends on size and material density of measured part [4].

2. Measurement

As an example part for measuring with all three systems was selected a part, which has suitable properties for scanning with different methods. Every system has its own benefits and limitations. The most significant parameters are size of the part, stiffness, material density, surface quality and accessibility to measured areas.

To achieve of all those conditions the part from fig. 3 that is suitable for measurement with all systems was selected. The part is an aluminum-silicone composite with maximal diameter 83 mm. Demonstration of possibilities and problems which can occur during measuring surface points and evaluating of selected form characteristics was performed. On the right side of the fig. 3, the contour created as intersection of the datum plane (Plane 1) and cylindrical surface demonstrates the trajectory for point collection. This contour is situated 2 mm under the top planar surface. The same measurement plan which was created in metrology software Calypso 4.4 for tactile probe was imported to the Calypso 4.8 for evaluation on point cloud from Metrotom scanning. The measurement plan for optical scanning was slightly accommodated, because it was not possible to scan in depth 2 mm from upper surface. The points on the edge of upper surface were scanned with optical sensor. It was assumed that form deviations on both trajectories are almost same, because they are very close together and part is the most significantly deformed in radial direction.



(a) (b)

Fig. 3. (a) Photo of measured example part and (b) CAD model of the part with selected trajectory for form evaluation.

3. Evaluation

Many kinds of analysis and comparisons were elaborated. Due to the limits of this only some points of attained results are presented. Advantages, disadvantages and selected parameters influencing measuring process of roundness and free-form contour are mentioned.

Every of the mentioned methods are favorably or unfavorably effected by various factors. In the following chapters are described the dominant factors influencing the process of measurement.

3.1. Influences of tactile probe

The tactile probe scanning is the most widely used method of measurement with CMM. It is ideal for parts which are not deformable by scanning force.

For time effective evaluation of form deviations it is strictly recommended to use measuring scanning system, because for this type of evaluations it is necessary to collect tens or even hundreds of points. With switching scanning system measuring of each point requires a scanning time of the order of seconds. Measuring head doesn't move out of contact after every point and therefore the scanning time rapidly decreases.

Spherical tips are normally used as universal probe elements in CMMs with mechanical probing. Geometry of the scanning sphere (especially diameter) determines influence of so-called mechanical filter. The bigger diameter of the sphere means more filtered data. The probe tip diameter should generally be as small as possible. It should normally remain bellow the limit which, when exceeded, produces mechanical filtering.

Example of problematic area where mechanical filter modifies the profile of the rib con-tour due to the mechanical filtering is presented on fig. 4. There are demonstrated three methods of profile creating. First one which most perfectly describes real contour is obtained as extraction from point cloud; second and third ones are obtained from tactile probe scanning. Difference between second and third is in diameter of ruby scanning sphere. Parts of the profile which can not be reached with scanning sphere do not correspond to real profile.

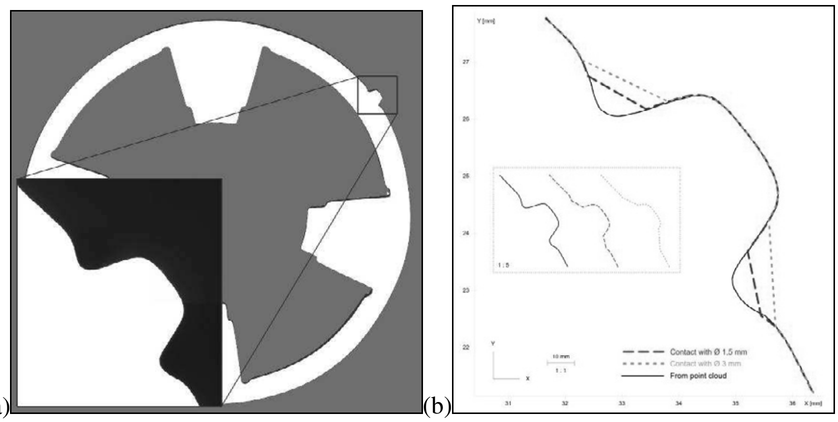
(a) 

Fig. 4. (a) Detail to the rib on outer cylindrical surface and (b) curves of the rib surface acquired from touch scanning with stylus tips with diameter 1,5 mm and 3 mm and from point cloud obtained from CT scanning.

3.2. Influences of camera system

The basis for every optical measurement is to display the features being measured with a highly accentuated contrast. This can be achieved best on the outer edges of objects.

Many types of illumination can be used for measuring machines. Transmitted light suit-able for flat objects, bright field reflected light and dark field reflected light are mostly used. ViSCAN sensor is basically installed with ring of LED around the camera. Segments of LEDs can be separately controlled so the directional light can be also used.

Contours are extracted from image using suitable mathematical algorithms in automatic mode or manually by operator. Surface contaminations, low contrast and brightness or inappropriately defined strategy can negatively influence results of measurement.

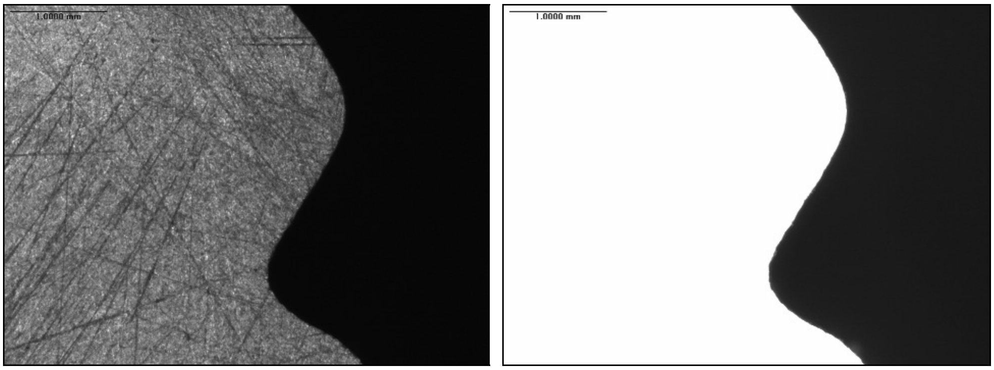


Fig. 5. Different intensities and directions of light set different contrast and brightness of the image.

3.3. Influences of computed tomography

Computed tomography measurements are influenced by the CT device (x-ray sources, detector, enclosure, axes), the application (test object, measurement parameters), the analysis (reconstruction software and data analysis), ambient conditions (temperature, humidity, vibrations, dust) and the operator (measurement strategy and its implementation). The sensitivity to specific measurement errors differs depending on the type of measurand. Geometric measurements are highly sensitive to absolute scale errors (wrong voxel size) and to the incorrect determination of threshold values for surface extraction from the point cloud.

On the presented part is demonstrated the negative influence of material inclusions with different density. Inclusion of high density near the surface (fig. 6) causes false peak on the surface extracted from point cloud. On the real surface there is no significant peak. This false peak appears due to the scattering of x-ray beams during scanning of the object.

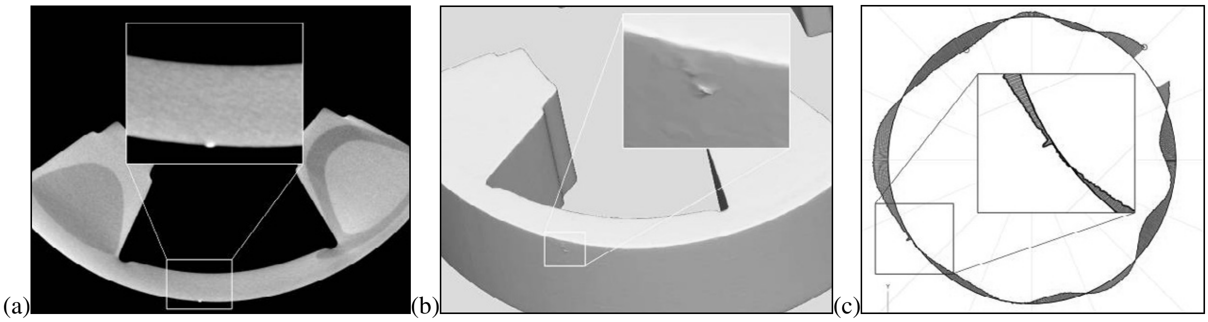


Fig. 6. (a) Cross-section of point cloud with the significant inclusion of material with higher density and (b) detail to the deformed surface of STL file and (c) graphical interpretation of roundness evaluation with peak at area of inclusion.

3.4. Influences of software filtering

Low-pass filters are normally used in form measuring technology for the digital filtering of measured profiles. These filters allow long-wave signal components to pass virtually un-damped. Short-wave signal components (e.g. caused by roughness), are very strongly damped. Used type of filter has a significant effect on the test result. The filter stage is specified as cut-off frequency for undulations per revolution for measurement of rotational bodies.

As an example Gaussian filer for eliminating short-wave signal on data from tactile scanning system was used (fig. 7).

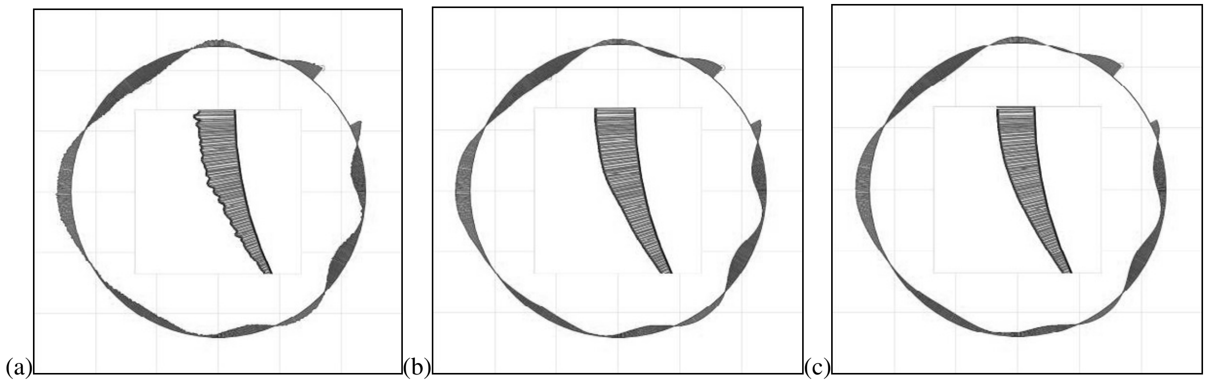


Fig. 7. Software filtering for (a) unfiltered profile and (b) Gauss filter with 50 upr. and (c) Gauss filter with 15 upr.

4. Results

This paper describes possibilities of measurement of selected part with three different scanning systems. Results of measurement of roundness declaring suitability of all three systems for measuring of selected characteristic are presented in the Tab. 1. Graphical interpretation of the results is shown on fig. 8. All profiles are unfiltered with almost same numbers of points.

Table 1. Summary of the results

	Average (mm)	Range (mm)	No. of scans	No. of points
Tactile sensor with 1,5 mm sphere	0,58613	0,00185	10	1032
Tactile sensor with 3 mm sphere	0,58564	0,00190	10	1032
Optical sensor	0,57616	0,00604	3	964
X-ray tomography	0,57852	0,00175	3	1000

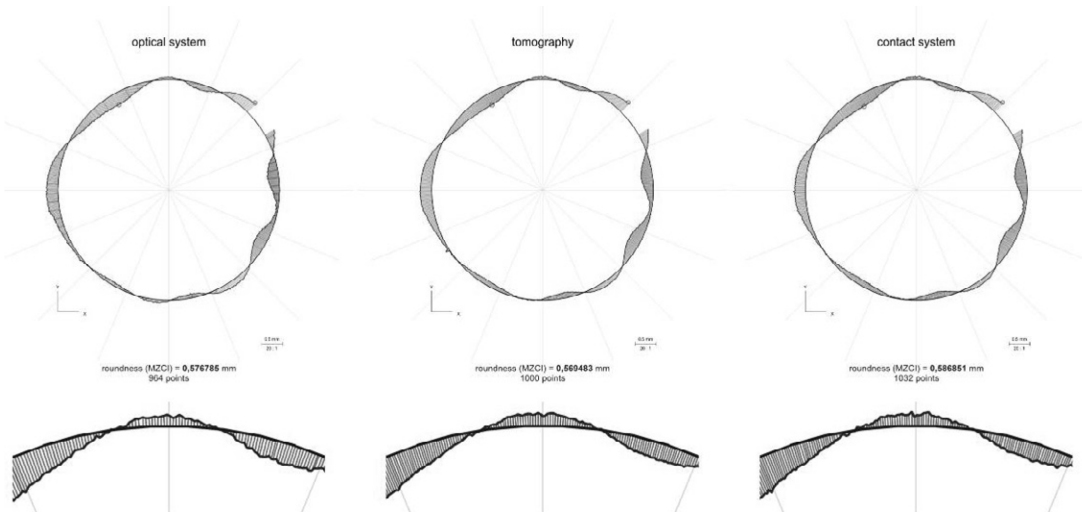


Fig. 8. Roundness deviations for all three methods with detailed views to selected areas.

5. Conclusion

About 85% of measuring processes in industry relate to form evaluation. Possibility to estimate cost-efficient measurements with coordinate measurement machines is achieved by using of contact and contactless measuring methods.

Usually it concerns the time necessary for measurement and accuracy. It means to measure as precise as necessary and not as precise as possible. Results of round deviation measurements are compared in this contribution. Results of measurements allow determination of optimal measuring strategy and improvement of measurement.

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